Red and Threat: Influences of Colour on Motor Performance during Bimanual Tasks

By

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Statement of Sources

I declare that this report is my own original work and that contributions of others have been duly acknowledged.

Signed: .....

Dated: .....

Acknowledgements

I would like to express my sincere gratitude firstly to the University for a wonderful 4 years of study; they have been long, and exhausting, but most importantly inspiring, I am now excited to begin my future – whatever it may bring. Secondly, I thank my supervisor, Dr Mike Garry, for your assistance and help throughout the year, for all the reading that you have done, for your answers the multitude of questions, and your – much appreciated – help with statistical analyses. Finally, I am forever indebted to my family and friends who have lent support, listened to my rambling, and who have understood the stress that such a year can bring.

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Abstract

The present study was designed to investigate the influence of the colours red and green on participant's performance of both unimanual and bimanual motor tasks. Three hypotheses were proposed; these predicted that reaction time would be decreased and maximal force output would be increased when tasks were completed in the presence of the colour red – as compared to green, and when tasks were completed unimanually – as compared to bimanually; lastly it was proposed that the two colours would differentially affect the strength of the bimanual deficit. Participants (12 female, 8 male) were aged between 18 and 45 years; free of any colour vision deficiencies, or motor issues; and self-reported to be right hand dominant. Participants completed the Purdue pegboard, used as a measure of manual dexterity, and a pinchgrip task, used as a measure of reaction time and maximal force output. Results indicated that movement type (uni- vs bi-manual) significantly influenced participant performance for the pegboard, but not for the pinchgrip task. In contrast, colour (red vs green) significantly influenced reaction time for the pinchgrip task, but did not affect any further variables. Overall, the present study did not provide conclusive evidence to support the proffered hypotheses.

Embodied cognition is a theoretical construct which holds that cognitive processes – and thus an individual's actions – may be influenced by the body's interaction with the environment (Wilson, 2002). In contrast to previous theories that emphasise only the influence of the mind on the body, embodied cognition theorists posit that the mind and the body work in tandem, such that the environment can both limit and guide the cognitive processes and learning of an individual (Gallese & Lakoff, 2005). In this manner, Kahol, Vankipuram, and Smith (2009) suggest that cognitive processes develop as a result of real-time, goal-directed interactions between the individual and their environment. One such construct which can influence an individual's functioning is colour.

The Colour Red

In the most basic sense, colour can have a profound influence on both human behaviour and psychological functioning. It stimulates decisions made by individuals; with each colour carrying a specific meaning, and the potential to convey specific information (Elliot & Maier, 2007). Used extensively in both nature and culture, colour acts as a powerful signal with the potential to convey two basic kinds of message: that of repulsion and that of attraction (King, 2005). While this is a widely accepted premise, historically, there has been no theoretical construct developed, and little empirical evidence, to support the notion (Fehrman & Fehrman, 2004).

Consequently, it is for this reason that researchers Elliot, Maier, Moller, Friedman, and Meinhardt (2007) developed what can be described as a general model of colour and psychological functioning. More recently, however, Elliot and Maier (2012) proposed the Colour-in-Context theory which expands on this relationship between colour and psychological functioning, and posits that the

perception of colour can influence the affect, cognition, and behaviour of an individual. This theory proffers four crucial factors which determine the influence of colour perception on psychological functioning, each of which are discussed below.

The first of these premises, proposed by Elliot and Maier (2012), states that colour carries meaning. It is proposed in this theory, that there are two manners in which colour can influence psychology, these are through learned associations and through biologically based signal functioning. In this manner, learned associations are developed through the repeat pairing of certain colours with certain messages and situations. Once the link between that colour and message has been established, merely seeing the colour should elicit the appropriate cognitive, affective, or behavioural response that the original coloured stimuli produced (Baldwin & Meunier, 1999). In contrast, the biological factors which influence colour and behaviour relationships have developed over time and are intrinsically based. A result of evolution, Elliot and Maier cite that for humans and non-human species, both adult and infant, colour indicates fitness relevant information, contributing to the continuation of a species.

The second premise proposed by the Colour-in-Context theory (Elliot & Maier, 2012), states that colour-meaning links are context specific. Colour has the potential to indicate different meanings for different situations, and therefore necessitate different responses. For instance, positive associations will typically generate approach behaviours, while negative associations will elicit avoidance behaviour. In this manner, colour has the potential to evoke motivational processes to produce behaviour.

The third premise proposed by Elliot and Maier (2012) proffers that the influence of colour on psychological functioning is an unconscious process. The

researchers cite, in this instance, that colour has the potential for direct and automatic bearing on both an individual's cognitive processes as well as their emotional state. In this manner, colour acts as an implicit affective cue which works to produce appetitive or aversive appraisals of the environment, outside of one's awareness. More specifically, the researchers report that when questioned, participants did not indicate any awareness that a manipulation of colour had influenced their affect, cognitions, or behaviour.

Finally, the fourth premise of the Colour-in-Context theory (Elliot & Maier, 2012) states that this relationship between colour and psychological functioning is reciprocal. That is, not only can colour influence psychological function, but psychological functioning may also impact on an individual's perception – and preference for – colour (e.g., Fetterman, Robinson, Gordon, & Elliot, 2010; Mitterer, Horschig, Musseler, & Majid, 2009). In this way, different situations can elicit unique emotional and behavioural responses, which in turn can produce unique perceptions of both the hue of a colour and how pleasing it is.

Currently, there is much contention in regards to the mechanisms which underlie the differing effects of colour. For example, in a paper written by Mollon (1989), the author suggests that the evolution of colour vision in humans facilitates both survival and reproduction. In this instance, colour serves as a signal function, allowing for humans – and animals alike – to engage in fitness-relevant behaviour such as a fight, or a flight, response. In a more specific sense, the complexion of an individual, that is the colour of their skin, can inform another of both their physical health and of their emotional state; thus providing information about any potential behavioural predispositions; aiding in the identification of potential mates, and of potential threats.

Red, perhaps the most influential colour studied in the present literature, is believed to represent the deepest, most visceral of emotions (Lobel, 2014). Associated with threat and violence, fight or flight, passion and lust, anger, and dominance; red is provocative, rousing behaviour and inciting activity. As described by Goldstein (1942), in what is believed to be one of the first papers investigating the effects of colour, red is most commonly associated with emotionally determined actions, it afflicts the organism, and evokes feelings of obtrusion, disturbance, and disagreeableness. While perhaps a rather extreme description, the activating effects of the colour red on behaviour have been demonstrated throughout the literature using many different methodological approaches. A number of studies have demonstrated, for example, that red can cause individuals to exhibit more deviant behaviour (Goldstein); a heightened sense of physiological excitation and arousal (Wilson, 1966); aggressive responses to traffic conditions (Gueguen, Jacob, Lourel, & Pascual, 2012); and an enhanced attractiveness and sexual desirability to the opposite sex (Elliot & Niesta, 2008).

In response to previous research demonstrating the extreme nature of effects generated by exposure to the colour red, Kuniecki, Pilarczyk, and Wichary (2015) conducted a study to investigate both the positive and negative connotations of this colour, and the role of emotional valence on the extent to which coloured stimuli attract attention. Outcomes from both motor responses and event-related potentials led these researchers to conclude that emotional contexts have the potential to alter the impact of colour on both attention and motor behaviour; a conclusion which follows Elliot and Maier's (2012) Colour-in-Context framework. In a more generalised sense, this is perhaps a result of – and reason for – the use of red in a

signalling context. Both in the natural world (Humphrey, 1976), and in a more urban environment, red acts as a warning, drawing attention and necessitating a response.

The premise that red is employed in signalling contexts to act as a warning has been additionally discussed in a paper by Changizi, Zhang, and Shimojo (2006); these researchers argue that the sole purpose of the evolution of colour vision in humans and primates was the perception of skin colour signalling. Changes in the colour of an individual's skin demonstrate altered functioning of their biological systems, and thereby act as a warning against mood fluctuations in conspecific members. More specifically, research has shown that even by simply dressing a male in red clothing influences the judgements made by others in regards to their perceived status within a group (Elliot et al., 2010). As such, it is believed that this status is based on an inherent judgement as to the threat of possible physical dominance from the individual (Re, Lefevre, DeBruine, Jones, & Perrett, 2014).

Evidence further supporting this relationship between the colour red and skin signalling was addressed in a study by Elliot and Aarts (2011). In this instance, the researchers promote a concept labelled the 'threat-behaviour' link which examines the influence of threat on the activation of animal behaviour. Mitigated by the need for rapid and emphatic responses when faced with threatening stimuli, it is thought that activation of the autonomic nervous system facilitates those behaviours required for fight or flight responses. The researchers further cite evidence supporting the relationship between the colour red and threat warnings (e.g., Elliot, Maier, Binser, Friedman, & Pekrun, 2009; Moller, Elliot, & Maier, 2009); and as such, propose that given the links between red and threat, and threat and motor output, perception of this colour produces a response similar to if exposed to the threat itself, therefore resulting in increased force and velocity of motor output.

Tested within a laboratory setting, Elliot and Aarts (2011) employed the use of both a pinchgrip and a handgrip task to investigate this hypothesis, which was supported, and thus the researchers concluded that not only was motor force significantly increased in the presence of red, but so too was the rapidity of this force onset. In this manner, it was demonstrated that indeed, in this instance, exposure to the colour red influenced stronger and more rapid responses from participants; responses which are utilised for instances in which individuals are exposed to threatening stimuli.

As discussed in their general model of colour and psychology, Elliot et al. (2007) further propose that colour associations, in particular the relationship between red and threat, perhaps arise from an interaction between not only biological predispositions but also learned associations. Dependent on repeated encounters, humans are taught from childhood that red is to be associated with hazardous and dangerous situations (e.g., warning signs; Or & Chan, 2010), mistakes (e.g., red pen corrections; Lichtenfeld, Maier, Elliot, & Pekrun, 2009), and avoidance behaviours (Mehta & Zhu, 2009).

In this manner, given these associations between red and danger, Maier, Elliot, and Lichtenfeld (2008) conclude that red is taught to implicitly evoke those behaviours related to stress and threat, thus activating an individual's autonomic nervous system and eliciting a response similar to that of fight or flight. While the use of red in such contexts is taught to warn of danger or the need for caution, it is unlikely that this colour plays a purely arbitrary role. Indeed, the Colour-in-Context theory (Elliot & Maier, 2012) suggests that it is perhaps an interaction between learned associations and biological dispositions that influences colour associations. Further, the selection of red colouring for hazardous warnings is likely to be a

response to its intrinsic effectiveness, and therefore acts to reinforce those biologically based response tendencies (Feltman & Elliot, 2012). In a similar manner, explanations for colour associations, which build on evidence from both socio-cultural and biological theories, allow too for association differences between separate contexts and cultures which can often be observed in the literature (e.g., Block & Kramer, 2009; Labrecque & Milne, 2011).

While evidence within the literature supporting the relationship between the colour red and the activation of behaviour is extensive, there are still those studies which have found either no or, in some instances, an opposite effect. For example, in a study investigating performance and self-rated arousal, Ainsworth, Simpson, and Cassell (1993) reported no significant effect of colour when participants were asked to complete tasks in either a red, a blue-green, or a white painted room. Similarly, Mehta and Zhu (2009) used the colours red and blue to test performance on cognitive tasks. Their results indicated that each colour enhanced performance on different types of tasks: red on a detail-oriented task, and blue on a creative task. Further analyses of different contexts led these researchers to conclude that these effects are a product of influences outside of the individuals' consciousness, that is, one is completely unaware of it. Further, in research conducted by Payen et al. (2011), participants were asked to perform a maximal voluntary contraction both prior to and following exposure to red, a chromatic colour, or an achromatic colour. Results demonstrated that viewing red inhibited the rate of force development, but had no effect on the peak force produced by individuals.

The Bilateral Deficit

The bilateral deficit is a phenomenon whereby the performance of tasks that involve bimanual movement is poorer than that of tasks which involve unimanual

movement (e.g., Li, Zatsiorsky, Li, Danion, & Latash, 2001; Ohtsuki, 1994). Research has demonstrated that not only is there deterioration in the performance of each limb when performing bimanual motor tasks, but Li et al. found that the maximal force output from simultaneous bilateral exertions is less than the sum of unilateral, single-limb, exertions. By definition, this deficiency in output is demonstrated only when homologous limbs are used (e.g., both arms) to perform simultaneous, synchronous movements (Jakobi & Chilibeck, 2001).

Research conducted by Bloom and Hynd (2005) demonstrated that the bilateral deficit is best explained with the theory of interhemispheric interference. This idea suggests that the corpus callosum performs an inhibitory function between the two hemispheres of the brain to allow for greater and more efficient intrahemispheric processing (Bloom & Hynd, 2005). Interhemispheric interference is utilised by the brain in most of an individual's day-to-day activities, whether it be tying a bow or simply walking, we must coordinate movement patterns that require each limb to produce different actions to accomplish a single goal (Fujiyama, Hinder, Schmidt, Garry, & Summers, 2012). As a result of this interference, as previously noted, performance of some motor tasks can be impaired; for example, force is reduced when performing bilateral contractions, and reaction time is longer for bilateral movements as compared to unilateral movements. While the presence of the bilateral deficit results in reduced performance for such individual measures of motor output, it also facilitates more efficient interlimb coordination (Vieluf, Godde, Reuter, & Voelcker-Rehage, 2013). In this manner, therefore, the bilateral deficit not only aids in completion of tasks but also allows for better and more efficient achievement of physical goals.

The involvement of the corpus callosum in interhemispheric interference is perhaps demonstrated most clearly in research conducted by Gazzaniga and Sperry (1966). In this instance, both control participants and patients who had had their hemispheres surgically separated were tested on a simple motor task. Individuals were asked to generate either unimanual or bimanual responses to two choice reaction time tasks presented to each visual field, and therefore each hemisphere, simultaneously. Results showed that although there was an overall increase in reaction time for the patients, they did not demonstrate any additional reaction time increase for bimanual conditions, this is in contrast to those control participants with intact corpora callosa, whose bimanual, as compared to unimanual, reaction times were greater. In this manner, researchers Gazzaniga and Sperry concluded that not only does the corpus callosum physically unite both cerebral hemispheres, but it acts to ensure that each works in harmony when occupied with a similar task. Thus, if separated, each hemisphere is capable of working on tasks in isolation.

Similarly, the current literature exploring the bimanual deficit and interhemispheric interference has further benefited from the employment of participants with Tourette's syndrome. This research has demonstrated an additional increase in reaction time, and therefore a stronger influence of the bimanual deficit, for those with the syndrome as compared to control participants. These studies have employed a range of methods including functional measures of interhemispheric interference using transcranial magnetic stimulation (TMS; Baumer et al., 2010), a sequential finger and thumb tapping task (Avanzino et al., 2011), and motor performance tests such as the Purdue pegboard task (Neuner et al., 2012).

More specifically, Margolis, Donkervoort, Kinsbourne, and Peterson (2006) used participant scores on the Purdue pegboard to investigate the different intensities

of the bilateral deficit for both control participants and those suffering from Tourette's syndrome. These researchers furthered previous research by investigating the correlation between scores on the pegboard task and corpus callosum size for each group of participants. Results demonstrated significantly larger corpus callosum sizes and significantly greater reaction times for those with Tourette's as compared with healthy individuals. In this manner, the researchers concluded that these participants were unable to sufficiently integrate motor performance across the hemispheres, a result again consistent with the proposed mechanism of interhemispheric interference.

The current literature focusing on the bilateral deficit and motor performance is extensive and has been investigated with a range of different tasks (e.g., Henry & Smith, 1961; Olafsdottir, Zatsiorsky, & Latash, 2005; Taniguchi, 1999). For instance, research by Vieluf et al. (2013) was conducted to investigate the effect of age and expertise on the magnitude of the bilateral deficit. In this instance, the researchers employed both novices and experts of fine motor skill, in three age groups: young, middle-aged, and late middle-aged. A further variable of movement was also investigated and thus both static and dynamic tasks were completed. Three results of significance were reported by Vieluf, Godde, Reuter, and Voelcker-Rehage; the first showed that the bilateral deficit was more pronounced in the static as compared to the dynamic task; secondly it was more pronounced in early and late middle-aged participants as compared to the younger groups; and finally, it was lower for experts as compared to novices.

Further research supporting the influence of inhibition on the bilateral deficit was conducted by Oda and Moratani (1995). In that study the researchers measured cortical involvement during maximal bilateral and unilateral handgrip contractions

using movement-related cortical potentials. Results of this task found that in addition to a reduction in force output for bilateral as compared to unilateral conditions, there was also a depression in cortical activity in the motor cortices, as measured by electroencephalogram (EEG). In this manner, Oda and Moratani concluded that the inhibition of force output, and thus the origin of interhemispheric interference can be found in the motor cortex. In contrast, more recently, researchers Post et al. (2007) measured brain activation during both bimanual and unimanual maximal isometric contractions. During these bimanual conditions, the researchers found, in addition to a reduction in force output, a decline in the activation of the precentral gyrus. This led Post et al. to conclude that contrary to previous research the origin of the bilateral deficit is not within the primary motor cortex.

Similarly, a further study designed to investigate this phenomenon was conducted by Taniguchi, Burle, Vidal, and Bonnet (2001). In this instance, the researchers aimed not only to provide evidence for the bilateral deficit but also to determine the location of a possible brain correlate, and thus mechanism, for the process. Employing the use of a specialised computer program, participants were required to respond to each stimulus with either a unimanual or bimanual finger flexion. Cerebral electrical activity was measured with an EEG during both a preparatory and an execution period, and results demonstrated weaker activation of the sensorimotor area involved in voluntary control for responses generated bilaterally as compared to unilaterally. In this manner, Taniguchi et al. concluded that the bilateral deficit is purely motor in nature, and therefore can be found to be a result of transcallosal inhibitory activity, as has been previously discussed.

Despite the inconclusive nature of results investigating the specific brain mechanisms for the bilateral deficit, there remains a consensus in the literature that it

is a consequence of, as previously discussed, inhibition. As argued by Coxon et al. (2014), this inhibition is required for responses made bimanually because these movements are conceptually bound within a single action. This is especially true, it is believed, for those movements which involve the simultaneous contraction of homologous muscles (e.g., Wenderoth et al., 2009), an action which is similar to that utilised in a pinch – or hand – grip force task. In this manner, bimanual movements are controlled as one both within specific brain regions and across specific brain networks (Rech, Herbet, Moritz-Gasser, & Duffau, 2013; Swinnen & Wenderoth, 2004; Tanji, Okano, & Sato, 1988). Inhibition is thus required to ensure that limbs work in a synchronous manner and so that coordination of movement is maintained.

The inhibitory nature of interhemispheric communication during bimanual motor movement is crucial to maintain coordination between the two homologous limbs completing the task (Wenderoth et al., 2009). As has been previously demonstrated, however, this inhibition is related to poorer performance, for example, on more simple, isolated measures such as force output and reaction time (Fling et al., 2011). In contrast to studies which have investigated this concept in terms of an increase in inhibition, there are those which have been designed to investigate the bilateral deficit using an equal but opposite mechanism: a decrease in activation. For instance, research by Post et al. (2007) used functional magnetic resonance imaging (fMRI) to compare participant's brain activation patterns during both bilateral and unilateral contractions of the index finger. Results of this study demonstrated for bilateral – as compared to unilateral – movements, a decrease in the activation of the precentral gyrus, resulting in decreased force output and muscle activation. Further, in a study conducted by Van Dieen, Ogita, and de Haan (2003), results indicated that for bilateral finger flexors, as compared to those made unilaterally, there was both an

above average force deficit, as well as an accompanying reduction in voluntary activation.

Similarly, this previously described decrease in activation for coordinated bimanual movement was investigated by Heuninckx, Wenderoth, and Swinnen (2008). In this instance, a positive correlation was demonstrated between activation levels of the sensorimotor areas of participants, and motor performance. The researchers concluded that when required to produce complex, coordinated movements, these cortical regions engaged in compensatory activation so to better performance achievement. With this relationship, therefore, between the bilateral deficit and brain activation, changes in the magnitude of this deficit, may perhaps be used to investigate the extent to which external stimuli can influence the internal activation of different structures, such as the proposed behaviour activating effects of the colour red.

Present Research

In sum, the present research recognises the contradictory results in current literature looking at the impact of colour on human behaviour, and was thus designed to replicate this work and to potentially provide greater clarity of results. Focusing on the colours red and green, the purpose of this study was to investigate the effect of these colours on bimanual motor movement. The colour green was selected as the contrast of red in this study firstly because these colours are considered to be opposites of each other in most colour models (Fehrman & Fehrman, 2004), and secondly because research has demonstrated that these colours elicit different behavioural responses from individuals following exposure (Lichtenfeld, Elliot, Maier, & Pekrun, 2012). In view of this aim, three main hypotheses were developed.

The first of these predicted a significant influence of colour on manual dexterity and force output. In this manner, it was hypothesised that as a result of the activating effect of the colour red on behaviour, participants would demonstrate increased performance on a Purdue pegboard task, as well as a decrease in reaction time and an increase in maximal force output for a pinchgrip task when these were completed in the presence of red as compared to those completed in the presence of the colour green.

It was further predicted that a significant effect of movement type would be demonstrated in this study. More specifically, it was hypothesised that the influence of the bilateral deficit on motor output would result in reduced performance on the Purdue pegboard task, and for the pinchgrip task there would be an increase in reaction time and a decrease in maximal force production when completed with both hands simultaneously as compared to a singular hand.

Finally, it was predicted that the effects of the bilateral deficit would be reduced in the presence of the colour red as compared to the colour green. As previously discussed, research has indicated that the bilateral deficit results from transcallosal inhibition, thus it was presently expected that exposure to a red stimulus would result in a reduction of inhibition, and therefore a decrease in the strength of the bilateral deficit.

Method

Participants

Twenty participants (12 female, 8 male) were recruited through advertisements at the University of Tasmania's Sandy Bay campus and the university's online psychology research participation system, SONA. Ethics approval was obtained for this study from the Tasmanian Social Sciences Human Research

Ethics Committee (Appendix A). All participants gave consent in writing and 1 hour of course credit was offered to first-year psychology students. All other participants were entered into the draw for one of two $50 Coles/Myer gift certificates to compensate for their time.

Participants ranged in age from 18 to 45 years (M = 24.95 years, SD = 6.89 years). For inclusion in the study, each individual was required to have normal or corrected normal vision; and was self-declared free of any colour vision deficiencies, neurological issues, or muscular problems. All participants self-identified as right hand dominant, as measured by scores on a revised version of the Edinburgh Handedness Inventory (Appendix B; Oldfield, 1971). Participants reported a medial Laterality Quotient (LQ) of 0.75 (range 0.2 - 1.0). Individuals were randomly assigned to either a red (n = 10) or green (n = 10) condition and all tasks were completed with this colour manipulation.

Apparatus/Materials

A Purdue pegboard was employed in the present study as a measure of manual dexterity (Tiffin & Asher, 1948). The independent variable of colour was manipulated for this task by covering the pegboard with either a red – or a green – coloured overlay. This overlay was created with appropriately coloured card and then laminated.

A pinchgrip task was used for trials investigating participant strength and reaction time. Testing was conducted on a computer equipped with a 19 inch monitor, and responses measured using THA-100-Q model transducer. This included the transducer held between two Perspex discs, and had a diameter of 26 mm and a thickness of 15 mm. Responses were made by participants gripping the force transducer between the index finger and thumb of the right and/or left hand. Stimulus

presentation was driven by a custom computer program. The stimulus consisted of a central fixation point ("+") which was replaced by the word "SQUEEZE" acting as a cue for responses; this was positioned horizontally in the centre of either a red or green background. The stimulus word presented was coloured black, capitalised, and written in size 72 bolded Arial font. This cue was displayed for a total of 4 seconds so to indicate to participants how long to grip the transducer. A variable intertrial interval of between 8 and 10 seconds separated individual trials to prevent anticipation of responses. The saturation and luminescence of each colour was controlled using the Microsoft Office software package.

Procedure

Participants were seated comfortably; written and signed consent was obtained from each individual; and both verbal and written instructions were provided for participants. Personal demographics were collected using a modified version of the Edinburg Handedness Survey. Participants were randomly allocated to either experimental group and procedures were explained.

Trials involving the Purdue pegboard were administered following the instructions outlined in Tiffin and Asher (1948). Participants were seated comfortably in a position that allowed unrestricted movement over the entire surface of the board; and instructed to pick up a single peg at a time with their left hand, their right hand, or both hands simultaneously from the appropriate well at the top of the board. They were then instructed to place the peg(s) in the corresponding row, beginning with the top position. A demonstration of three or four pegs was given by the researcher but no practice trial was allowed so as to prevent any effects of learning (Noguchi, Demura, Nagasawa, & Uchiyama, 2006). Individuals were then given 30 seconds to place as many pegs as possible into the board. For each

movement condition – unimanual left or right, or bimanual – this task was repeated three times.

For trials involving the pinchgrip task, individuals were seated comfortably approximately one metre from the computer monitor, holding the force transducer loosely between the pulp of their thumb and index finger of each hand. Participants were instructed to respond as quickly and as forcefully as possible when presented with the stimulus and to hold the pinch for a period of four seconds, the duration of the word's display. A total of ten trials[1] were completed for each movement condition – unilateral left and right, and bilateral.

To reduce any confounding effects of learning, the order in which each task was completed was counterbalanced. In addition, there was a randomised order for the completion of each movement condition. Finally, to prevent fatigue, a break of approximately 2 minutes was given between the Purdue pegboard and pinchgrip tasks.

Design & Data Analysis

The present study employed a 2 (colour: red, green) by 3 (movement: unilateral left, unilateral right, bilateral) mixed design. A total of four dependent variables were measured: Purdue pegboard performance (number of pegs placed); and reaction time (ms), maximum force (a.u.), and force rise time (ms) for the pinchgrip task.

For the present study, statistical analyses were conducted using multilevel linear models with condition (red, green), movement type (unilateral left, unilateral right, bilateral), and trial (first, second, third) as factors. Separate analyses were made for each dependent variable. Pairwise post-hoc comparisons were made using

[1] A total of 3 participants, however, had only 9 trials

Fisher's Least Significant Difference (LSD) procedure. Purdue pegboard performance for unimanual trials was quantified as being the number of pegs placed within a single 30 second period, and for bimanual trials as the total number of pairs of pins.

For pinchgrip data, reaction time was quantified as the time at onset of the squeeze, measured in milliseconds, this variable indicated how quickly participants were able to react to the presentation of stimuli. Further, maximum force output was quantified as the largest deviation between the highest and lowest peaks within individual force trials. This variable was measured in arbitrary units (a.u.) and was used in this study simply to investigate whether force levels differed between conditions, but did not indicate the actual amount of force produced. Finally, the variable force rise time was quantified as the time between reaction time and the first plateau of force. This variable too was measured in milliseconds and provides a measure of how rapidly participants were able to generate force. For the pinchgrip task, data was checked for outliers in reaction time at individual level and at each level of movement type. In this manner, exclusions were made for trials with reaction time responses more than 2.5 standard deviations greater than an individual's mean reaction time to minimise the potential biasing influence of lapses in attention. If elimination was made on the basis of reaction time, that entire trial was excluded for all analyses. For all statistical tests, statistical significance was considered at $p < .05$.

Results

Purdue Performance

Performance of the Purdue pegboard task is summarised in Figures 1 and 2. Results indicated a significant main effect of trial, F (2, 144) = 3.60, p = .030, with an improvement in performance across the three trials (1st: M = 13.97 pegs, SD =

2.822; 2nd: *M* = 14.58 pegs, *SD* = 2.689; 3rd: *M* = 14.68 pegs, *SD* = 2.709). Post-hoc pairwise comparisons indicated that compared to the first trial, mean scores on the second (M_{diff} = 0.62, p = .035, 95% CI [.045, 1.189], d = .221) and third trials (M_{diff} = 0.72, p = .014, 95% CI [.145, 1.289], d = .257) were significantly better. There was no significant difference between the mean scores of the second and third trials (M_{diff} = 0.10, p = .730, 95% CI [-.672, .472], d = .037).

A further significant main effect of movement type was indicated in the data, F (2, 144) = 118.19, p < .001, with a decrease in performance moving from the unimanual condition with the right – dominant hand (*M* = 16.38 pegs, *SD* = 2.308), to the unimanual condition with the left – non-dominant hand (*M* = 14.85 pegs, *SD* = 1.973), and through to the bimanual condition (*M* = 12.00 pegs, *SD* = 1.887). Significant differences between each movement type were identified using pairwise comparisons, between unimanual left and bimanual (M_{diff} = 2.85, p < .001, 95% CI [2.278, 3.422], d = 1.476), unimanual right and bimanual (M_{diff} = 4.38, p < .001, 95% CI [3.811, 4.955], d = 2.079), and unimanual right and left (M_{diff} = 1.53, p < .001, 95% CI [0.961, 2.105], d = .713).

Finally, results indicated, for this task, no significant difference between the red (*M* = 14.43 pegs, *SD* = 3.006) and the green (*M* = 14.39 pegs, *SD* = 2.471) conditions, F (1, 18) = .005, p = .945, d = .015. Nor was there a significant interaction between colour and movement type, F (2, 144) = 2.29, p = .105.

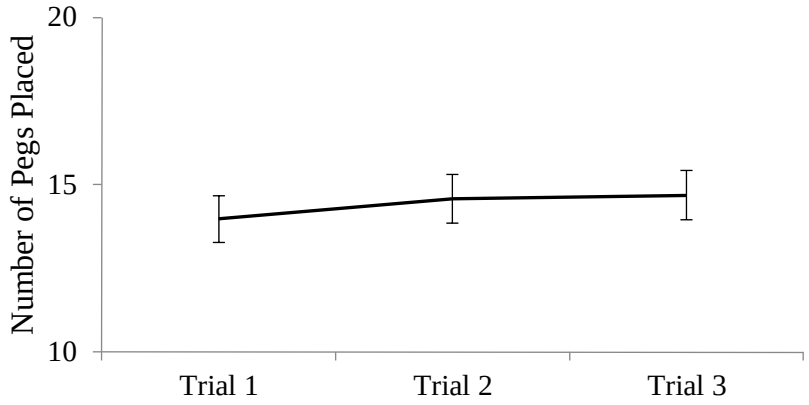

Figure 1. Mean Purdue pegboard score (95% CI) for each pegboard trial.

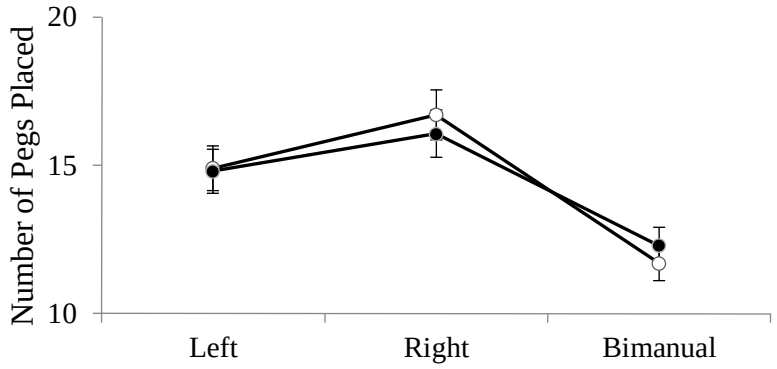

Figure 2. Mean Purdue pegboard score (95% CI) for red (–○–) and green (–●–) conditions across each movement type.

Pinchgrip: Reaction Time

Reaction time data for the pinchgrip task is summarised in Figure 3. Analysis of this data indicated no significant difference between each type of movement: unimanual left (M = 181.8 ms, SD = 33.05), unimanual right (M = 195.8 ms, SD = 57.73), and bimanual (M = 182.0 ms, SD = 30.62), F (2, 36) = 1.65, p = .207 (all d < 0.3).

In contrast to pegboard performance, pinchgrip data indicated a significant main effect of colour, F (1, 18) = 4.80, p = .042, d = .819, with a *slower* reaction time found for the red condition (M = 198.8 ms, SD = 49.70) as compared to the

green condition (*M* = 167.1 ms, *SD* = 22.94). However, again there was no significant interaction between colour and movement, *F* (2, 36) = .29, *p* = .749.

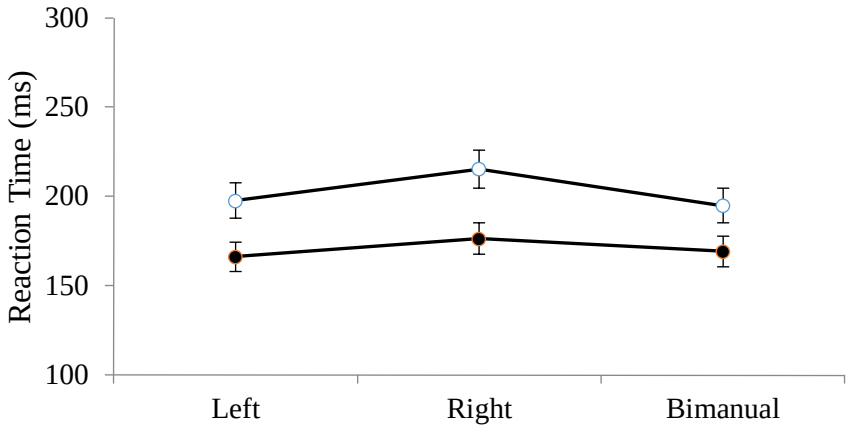

Figure 3. Mean reaction time (95% CI) for red (–○–) and green (–●–) conditions across each movement type.

Pinchgrip: Rise Time

Force rise time data for the pinchgrip task is summarised in Figure 4. Analysis of rise time indicated neither a significant difference between movement types, left (*M* = 357.1 ms, *SD* = 102.66), right (*M* = 348.6 ms, *SD* = 103.18), bimanual (*M* = 362.1 ms, *SD* = 81.23), *F* (2, 36) = .37, *p* = .698 (all *d* < 0.15); nor a significant difference between the colours red (*M* = 351.8 ms, *SD* = 84.86) and green (*M* = 360.1 ms, *SD* = 105.02), *F* (1, 18) = .04, *p* = .838, *d* = .087. There was also no significant interaction effect between these two variables, *F* (2, 36) = .66, *p* = .524.

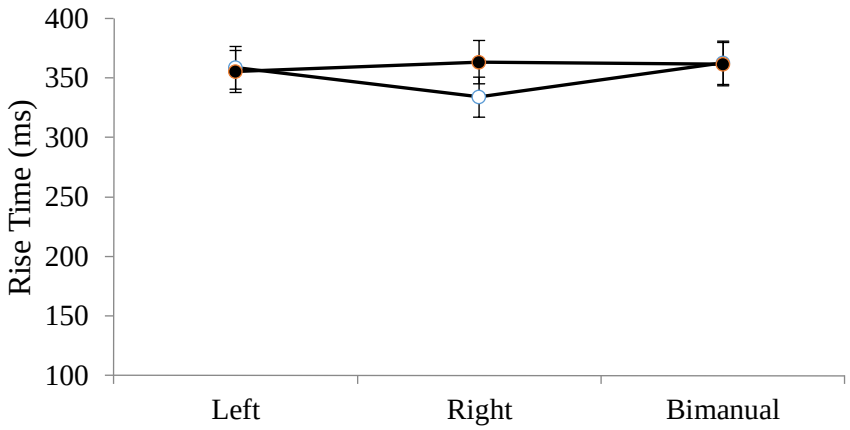

Figure 4. Mean rise time (95% CI) for red (–○–) and green (–●–) conditions across each movement type.

Pinchgrip: Maximum Force

Maximal force data for the pinchgrip task is summarised in Figure 5. Results from analysis of maximum force output again indicated no significant difference between movement types, left (M = 0.24 a.u., SD = 0.096), right (M = 0.26 a.u., SD = 0.064), bimanual (M = 0.24 a.u., SD = 0.101), F (2, 36) = .95, p = .398 (all d < 0.25); or between red (M = 0.23 a.u., SD = 0.073) and green conditions (M = 0.26 a.u., SD = 0.097), F (1, 18) = 1.11, p = .307, d = .420. Nor was there was there a significant interaction effect between colour and movement, F (2, 36) = 1.56, p = .224.

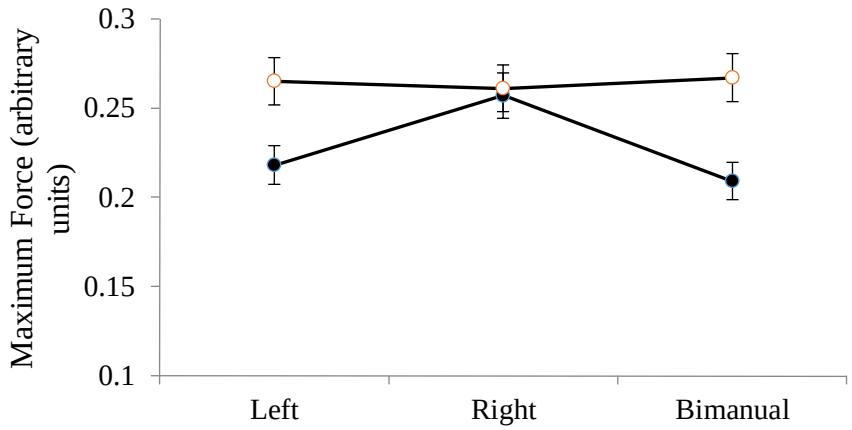

Figure 5. Mean maximum force produced (95% CI) for red (–○–) and green (–●–) conditions across each movement type.

Discussion

The present study investigated the influence of the colour red on motor performance for both unimanual and bimanual hand movements. Following a review of current literature, three hypotheses were proposed for this research. It was hypothesised that performance of both the Purdue pegboard and a pinchgrip task would be significantly increased both when tasks were completed in the presence of the colour red as compared to green, and when unimanual movements were used as

compared to bimanual movements. It was further hypothesised that there would be a significant interaction between these two factors, demonstrating, when compared to green, a reduction in the strength of the bimanual deficit for red conditions.

The main findings of this research indicated a significant effect of colour on the initial reaction time for a force task, demonstrating a reduction in speed for those in the presence of the colour red, as compared to the colour green. This effect was similar for all types of movement, both unimanual and bimanual, indicating no influence on the bimanual deficit for this task. A further finding that was demonstrated in this research relates to the influence of hand movement type on the performance of a task measuring manual dexterity. Here, data indicated a bimanual deficit in which performance of both hands working simultaneously was significantly reduced as compared to each hand working independently, so too was the performance of the non-dominant hand reduced as compared to the dominant hand of participants. Participants performed to a similar level across both conditions, and thus it was shown that a manipulation of colour did not significantly affect participants' manual dexterity. No further effects reached statistical significance, thus indicating that results only partially supported proposed hypotheses one and two. Further, results of this study did not provide any support for the hypothesis that colour would differentially affect the extent to which the bimanual deficit impacted on motor performance.

Given the ambiguity of results investigating the bilateral deficit for the present study, perhaps it is the nature of the individual task which influenced the findings. For example, as previously discussed, research conducted by Aune, Aune, Ettema, and Vereijken (2013) demonstrated a greater bilateral deficit for proximal muscles (e.g., the shoulder) as compared to distal muscles (e.g., the finger). In the

present study, therefore, the involvement of the entire arm required to complete the Purdue pegboard task may provide an explanation as to why a statistically significant deficit for bilateral conditions was seen for this task and not the pinchgrip task which involves movement of only the fingers. This finding is also consistent with earlier research by Latash, Li, Danion, and Zatsiorsky (2002) which demonstrated that although the proximal muscles of the arm generated an overall greater force output, the bilateral deficit percentage was larger in symmetrical tasks for movement of proximal muscles as compared to distal movements.

Further investigation of the influence of specific task demands may be demonstrated in two additional studies. The first of these, conducted by Franz and McCormick (2010), indicated a significant reaction time deficit of bilateral movement for a reaching task. A movement which is similar to that required to complete the Purdue pegboard. In a second study by Hoyer and Bastian (2013), participants were required to complete a maximal force pinchgrip task. Results of that investigation demonstrated that when performing symmetric forces, there was no significant bimanual deficit evident on motor planning reaction time. These findings are consistent with those of the current study, which indicate a significant bilateral deficit for only the pegboard task – a measure of manual dexterity – and not the pinchgrip task – a measure of force output.

As previously demonstrated in embodied cognition literature, the activation inducing properties of the colour red may allow for an increase in an individual's levels of arousal (Elliot, 2015; Robinson, 2004; Shibasaki & Masataka, 2014; Wilson, 1966). However, a possible explanation for the lack of significant findings for the present study may be related to the Yerkes-Dodson Law. This is an empirical performance paradigm which states that while a moderate level of arousal when

completing tasks can enhance performance, when these levels become too high a decrease in performance is seen (Chaby, Sheriff, Hirrlinger, & Braithwaite, 2015; Yerkes & Dodson, 1908). This was additionally discussed in a paper by Al-Ayash, Kane, Smith, and Green-Armytage (2015) who cite that the over-stimulating effects of the colour red may lead to distraction of attention, again leading to a decrease in performance levels. As such, the researchers empirically demonstrated this effect, reporting that exposure to the colour red – as compared to both yellow and blue – both increased participants' heart rate and impaired their scores on a reading comprehension task.

In a similar manner, and in support of this proposition, in a paper by Elliot et al. (2007) the researchers hypothesised that exposure to the colour red would impair outcomes on tasks completed in an achievement context. In this instance, it was believed that fear of failure would evoke avoidance motivation, ironically leading to a reduction in performance. Results of this study indicated that such impairment is evident not only using behavioural, but also psychophysiological, measures. Thus leading the researchers to conclude that colour certainly does influence behaviour, and at a level outside of an individual's psychological awareness.

In contrast to the work of Elliot et al. (2007), the present study was designed so to minimise any effects of competition or fear of failure. Instructions were presented in a neutral manner and testing was conducted individually, so that participants were required only to complete tasks to the best of their ability. Further, participants were kept blinded to the purpose of the study so to reduce any additional variables impacting on results. In this manner, this influence of competition and fear of failure was perhaps not as pronounced as in past research. As a result further factors impacting on results need to be considered.

For instance, Payen et al. (2011) have demonstrated empirically that viewing red, as compared to a similarly matched chromatic colour, may inhibit the rate of production, but not the peak amplitude, of output in a maximal voluntary contraction. This is a finding which is similar to that evident in the current study. Unlike that which was hypothesised, it was shown that while there was a lack of evidence for an influence of colour on the maximal force output, reaction time was increased for participants who completed tasks with red stimuli. In interpreting this result, Payen et al. address an anxiety-fear distinction and the influence of temporal distance on differences in motor production. A review of current literature indicates that a distal threat cue stimulates an anticipatory anxiety response, inhibiting motor production (Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009); while a proximal threat cue prompts a fear response, facilitating motor functioning (Coombes, Cauraugh, & Janelle, 2007). In the present study, therefore, the continued presentation of both colours, most particularly the colour red, may have elicited this anxiety response thus increasing reaction time for red conditions. In this manner, future research would possibly benefit from the presentation of a colour manipulation only when response is required and not before.

While, the belief that exposure to the colour red influences avoidance behaviour perhaps provides an explanation for the increase in reaction time of the red condition for the present study's pinchgrip task, further considerations must be made to interpret the lack of significant colour findings for other variables. In an achievement context such as this, it can be difficult to control for all motivational cues with the potential to impact on results. For this reason, it can often be unclear as to the extent to which other influences either interfere or promote specific effects.

Perhaps the most influential moderator of colour and its effects on motor behaviour in the current literature is emotion (Gilliam & Unruh, 1988; Kuhbandner & Pekrun, 2013; Maier, Hill, Elliot, & Barton, 2015; Warren et al., 2006). One such study designed to investigate this relationship was conducted by Kuniecki et al. (2015). In this instance, participants were required to complete a dot-probe task depicting two images matched for valence and arousal, and differing only in their colour with one being red. Researchers measured both reaction time and event-related lateralisation and demonstrated that not only did the red image initially attract attention but it also held it when the picture was emotionally positive or negative, but not when designed to be neutral. The researchers further reported for the neutral condition more pronounced early directing-attention negativity (EDAN) in the hemisphere ipsilateral to the stimulus, indicating a direction of attention away from the red cue. This finding was further supported in reaction time data in that responses were initiated more slowly following exposure to a red neutral – as compared to a red emotional – stimulus. In this manner, Kuniecki and colleagues concluded that for neutral images, even when coloured red, without an emotional context attention is less focused and is quickly directed away from the stimulus.

The results of this previous research can perhaps be used to explain the lack of findings in the present study. As before, Kuniecki et al. (2015) reported that without an emotional setting, the evolutionary significance of the colour red is rather superfluous and does not significantly influence an individual's motor behaviour. For emotional stimuli it was demonstrated there was a shift of attention, facilitating motor preparation and therefore decreasing reaction time. In the present study, it may simply be argued, therefore, that the indicated lack of significant difference between both red and green conditions results from a lack of emotional identification with the

colour red, subsequently nullifying any influence of a colour manipulation. This relationship between red, emotion, and performance has been further identified in additional studies such as those conducted by Kuhbandner and Pekrun (2013), and Moller et al. (2009), each of which demonstrated that the colour red improves both memory for, and reaction time to, respectively, words associated with failure, and words with an implicit, more general negative valence.

With interpretation of results, there must also be consideration of limitations for the current study. First, as discussed, the influence of colour on psychological functioning and behaviour is dependent totally on context (Elliot et al., 2007), and thus to a lesser extent the personal history of the individual. With no measure of personal valence for either red or green, it cannot be certain that during completion of tasks for the present research, participants indeed experienced emotional arousal as expected. Future research, therefore, would perhaps benefit from not only a self-reported measure of an individual's colour preference, but also a physiological measure of arousal.

A further consideration that must be made for this study refers to the assumed links between the colour red and threat, as well as threat and motor output. In this manner, it is proposed that red activates the same biological systems as threatening stimuli, and thus has the potential to elicit a response similar to if a threat were present. In the present study, the use of only static stimuli – for example a coloured background – is perhaps not sufficient to stimulate a significant difference in condition results. It is thought, therefore, that the use of more dynamic stimuli would generate a stronger response. Again, this was demonstrated by Kuniecki et al. (2015) who concluded from a study measuring both reaction time and event related lateralisation, that participants expressed faster reaction times and greater levels of

attention for red stimuli designed to elicit positive or negative emotions as compared to those designed to be neutral.

Thirdly, the nature of tasks used in the present study may have influenced the effect of colour on performance. For instance, each task was a measure of fine motor movement, and thus required exactness and control. In Goldstein's (1942) seminal study into the effect of colour on motor performance, it was argued that red – relative to green – impaired performance on tasks requiring precision. Further research of this nature has generalised such a concept, and it is now believed that these longer wavelength colours (e.g., red, yellow) reduce performance on more complex tasks as compared to those with shorter wavelengths (e.g., blue, green) as a result of the calming nature of the cooler colours (Elliot et al., 2007; Stone & English, 1998). Perhaps, therefore, the present research would benefit from tasks which involve only gross motor movements such as maximal voluntary contraction of muscle groups.

While results of the present study were inconclusive, there remain several implications of such colour research on different daily situations. Firstly, consideration must be made when designing visual based psychological assessments. In such an achievement context, it may be assumed that individuals will experience much greater emotional responses to such a situation and thus, results will be confounded. More specifically, as demonstrated by Elliot et al. (2007), exposure of individuals to the colour red prior to the completion of a test for intelligence quotient (IQ), both reduces their overall performance as well as influences them to avoid more difficult questions.

Further, institutions such as schools, which evaluate an individual's performance, must also consider the implications of such subconscious influences. The use of red ink to correct responses on a test, for example, has the potential to not

only influence a student's psychological functioning through the emotion driven link between the colour red and threat; but it also reinforces those learned associations between red and warnings (e.g., Lichtenfeld et al., 2009). Additionally, it was demonstrated by Maier et al. (2013) that when evaluating potential candidates for a job, participants judged individuals wearing a red shirt – as compared to green – as less intelligent; those with red accents on their tie – as compared to blue – as having reduced earning and leadership potential; and those wearing red as less likely to be hired. While not indicated by the results of the present study, these more applied learned associations cannot be denied. Whether the colour red has an implicit influence on human behaviour remains a topic of controversy in the current literature, however, as previously discussed, humans are taught from a young age that red represents warning and danger, and as such perception of this colour have the ability to alter an individual's behaviour.

Finally, while not indicated in the present study, the influence of the colour red on physical performance has been documented in previous literature. For example, in a paper by Hill and Barton (2005) the researchers argue that in sports and contests of physical strength, wearing the colour red is associated with a greater probability of victory. This notion was disputed by Hagemann, Strauss, and Leissing (2008) who believed that the discrepancy was a result of an attentional bias of the referee toward the red uniforms. However, the argument remains that the presence of red in a competitive situation has the potential to influence its outcome. Therefore, considerations should always be made as to the extent of this effect.

While the inconclusive nature of results from the present study may be due, in part, to methodological limitations or exclusions, it is additionally possible that the initial hypotheses guiding this research were incorrectly based on biased reports.

Previous research has been limited, for example, by a lack of methodological precision and an overall absence of specified theory based research. In regards to the generalisability of previous results, for example, Feltman (2012) argues that a lack of adequate colour specification in these studies means that it is impossible to compare studies according to the physiological properties – such as hue, luminescence, and chroma – of colour. Further, often within studies themselves, opposing colours have been utilised which have not been matched on these physiological aspects. In this manner, in Mehta and Zhu's (2009) study investigating the effect of red and blue on avoidance motivation, for instance, saturation and lightness were not matched between the two colours. Therefore, it is possible that differences between conditions may not have been a result of the researcher's manipulation of hue, but of another factor completely.

A further limitation of previous research is related to the lack of systematic empirical procedures used for research investigating the effect of colour on human behaviour. For example, the rationale of the present study, and thus the formulation of hypotheses, was grounded in Elliot et al.'s (2012) theory of Colour-in-Context. In this instance, the researchers provide an explanation for the relationship between a variety of both colours and outcomes. It was purposely designed not to restrict these explanations and to remain ambiguous. This theory, therefore, while useful in its general application for the interpretation of the relationship between colour and psychological functioning in many different contexts, is also limited because of this same feature. Is it that this ambiguity allows for connections to be made between the two variables in any situation? If so, it may be that there does not exist any significant influence of colour on human behaviour.

This point may be further supported by the lack of significant effects indicated in the present study. The possibility remains that over-interpretation of results in previous research may have resulted in false positive type 1 errors being inferred as meaningful. Again, this is consistent with results from previous research which have demonstrated null effects of colour manipulation (e.g., Ainsworth et al., 1993; Hatta, Yoshida, Kawakami, & Okamoto, 2002; Kwallek, Lewis, Lin-Hsiao, & Woodson, 1996; Stone & English, 1998; Suk & Irtel, 2010). In support of this bias due to increased type 1 errors, Rabelo, Keller, Pilati, and Wicherts (2015) conducted a meta-analysis to investigate the generalisability of results in studies of embodied cognition, the underlying basis of the present study. In that report, the researchers state that there is a tendency of journals to publish selected positive results and for an overestimation of effect sizes in the current literature. Further, they argue that these biases often result in inadequate empirical evidence for the construction of theoretical approaches and thus these frameworks are unsatisfactory for testing scientific claims. In this manner, perhaps then the null results demonstrated in the present study provide a more adequate indication of the relationship between colour and human behaviour. It may be, therefore, that additional research is required to further investigate the potential activating effects of the colour red and its subsequent influence on motor output.

In summary, therefore, the present study was designed to investigate embodied cognition, and the influence of colour on motor output. Due to its documented activating effect on behaviour, it was hypothesised that the colour red would differentially influence the strength of the bimanual deficit, as compared to the colour green. This hypothesis was not supported by responses made by participants in this study, demonstrating a lack of significant effect of both the colour and hand

movement conditions. This lack of significant results does, however, appear to provide support for Elliot and Maier's (2012) colour in context theory. It is perhaps the lack of emotional manipulation which has prevented more conclusive results.

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Appendix A

Ethics approval letter from Tasmanian Social Sciences HREC

Social Science Ethics Officer
Private Bag 01 Hobart
Tasmania 7001 Australia
Tel: (03) 6226 2763
Fax: (03) 6226 7148
Katherine.Shaw@utas.edu.au

HUMAN RESEARCH ETHICS COMMITTEE (TASMANIA) NETWORK

30 June 2015

Dr Michael Garry
Psychology
Private Bag 30

Dear Dr Garry

Re: FULL ETHICS APPLICATION APPROVAL
Ethics Ref: H0014923 - The effects of colour and future thinking on motor behaviour

We are pleased to advise that the Tasmania Social Sciences Human Research Ethics Committee approved the above project on 30 June 2015.

This approval constitutes ethical clearance by the Tasmania Social Sciences Human Research Ethics Committee. The decision and authority to commence the associated research may be dependent on factors beyond the remit of the ethics review process. For example, your research may need ethics clearance from other organisations or review by your research governance coordinator or Head of Department. It is your responsibility to find out if the approval of other bodies or authorities is required. It is recommended that the proposed research should not commence until you have satisfied these requirements.

Please note that this approval is for four years and is conditional upon receipt of an annual Progress Report. Ethics approval for this project will lapse if a Progress Report is not submitted.

The following conditions apply to this approval. Failure to abide by these conditions may result in suspension or discontinuation of approval.

1. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval, to ensure the project is conducted as approved by the Ethics Committee, and to notify the Committee if any investigators are added to, or cease involvement with, the project.

2. Complaints: If any complaints are received or ethical issues arise during the course of the project, investigators should advise the Executive Officer of the Ethics Committee on 03 6226 7479 or human.ethics@utas.edu.au.

3. Incidents or adverse effects: Investigators should notify the Ethics Committee immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.

4. Amendments to Project: Modifications to the project must not proceed until approval is obtained from the Ethics Committee. Please submit an Amendment Form (available on our website) to notify the Ethics Committee of the proposed modifications.

5. Annual Report: Continued approval for this project is dependent on the submission of a Progress Report by the anniversary date of your approval. You will be sent a courtesy reminder closer to this date. **Failure to submit a Progress Report will mean that ethics approval for this project will lapse.**

6. Final Report: A Final Report and a copy of any published material arising from the project, either in full or abstract, must be provided at the end of the project.

Yours sincerely

Natasha Jones
Administration Officer, Ethics

Appendix B

Revised version of the Edinburg Handedness Inventory

*Participant ID:*_____

D.O.B: _____ Sex: _____

- Please indicate your preferences in the use of hands in the following activities by *putting + in the appropriate column*. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put* ++. If any case you are really indifferent put + in both columns.
- Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.
- Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	Left	*Right*
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking Match (match)		
10. Opening box (lid)		

L.Q.	Leave these spaces blank	DECLE

Appendix C

Participant Information Sheet and Consent Form

Colour and Human Movement

Invitation

To the participant

You are invited to participate in a study looking at colours and their effect on movement. This research is being conducted as part of an Honours Project at the University of Tasmania by student researcher, Sarah Nichols, under the supervision of Dr. Mike Garry, Director of Learning and Teaching, Faculty of Health, Psychology Department.

What is the purpose of this study?

The aim of this study is to determine the effect of colour on human movements in terms of the force used and the precision of hand movements.

Why have I been invited to participate?

Anyone aged between 18 and 45, who is free from known neurological disorders, has normal or corrected-to-normal vision and is not colour blind is invited to participant in this study. Participation in this study is voluntary and participants have the right to withdraw at any time without penalty.

What will I be asked to do?

You will be asked to participate in two movement tasks. One will involve placing as many small pegs in a board as you can in 30 seconds. The other will entail pinching a small disc-shaped force measurement device quickly and forcefully between the index finger and thumb. These tasks will be done with your left hand, right hand and both hands.

This will take place at the University of Tasmania, Sandy Bay Campus in the Human Motor Control Laboratory. It is expected to take approximately one hour to complete.

Are there any possible benefits from participation in this study?

Participants will have the chance to win one of two $50 Coles/Myer gift voucher or, for first year psychology students at the University of Tasmania, receive one hour research participation credit.

The findings from this study will contribute to a greater understanding of human movement and behaviour.

Are there any possible risks from participation in this study?

The risks involved in this study are minimal. Movement tasks could result in minor fatigue.

What if I change my mind during or after the study?

You are free to change your mind and withdraw from the study at any time. This can be done without explanation to the researcher. Your data will be coded to protect your identity and as a result may be withdrawn at any point.

What will happen to the information when this study is over?

Data from this study will be treated in a confidential manner. You will be assigned a code number, by which your data can be re-identified.

The data for this study will be kept for at least five years from the date of publication and then destroyed. Data will be stored on a password-protected computer in a restricted access area of the University of Tasmania.

How will the results of the study be published?

A summary of the findings from this research will be published on the School of Psychology webpage (http://www.utas.edu.au/psychology/home) available from mid-October onwards.

What if I have questions about this study?

If you have any questions or concerns in regards to this study, please do not hesitate to contact us.

Student researcher: Sarah Nichols sarahn1@utas.edu.au

Supervisor: Dr. Mike Garry michael.garry@utas.edu.au

This study has been approved by the Tasmanian Social Sciences Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study, please contact the Executive Officer of the HREC (Tasmania) Network on +61 3 6226 6254 or email human.ethics@utas.edu.au. The Executive Officer is the person nominated to receive complaints from research participants. Please quote ethics reference number [**H0014923**].

This information sheet is for you to keep, so you can refer to it later if needed.

Colour and Human Movement

Participant ID: _____

For Participants

1. I agree to take part in the research study named above.
2. I have read and understood the Information Sheet for this study.
3. The nature and possible effects of the study have been explained to me.
4. I understand that the study involves performing hand movement tasks. The expected time required for participation is one hour.
5. I understand that participation involves the risk(s) of minor fatigue.
6. I understand that all research data will be securely stored on the University of Tasmania's premises for five years from the publication of the study results, and will then be destroyed.
7. Any questions that I have asked have been answered to my satisfaction.
8. I understand that the researcher(s) will maintain confidentiality and that any information I supply to the researcher(s) will be used only for the purposes of the research.
9. I understand that the results of the study will be published so that I cannot be identified as a participant.
10. I understand that my participation is voluntary and that I may withdraw at any time without any effect.
    If I so wish, I may request that any data I have supplied be withdrawn from the research until September 1, 2015.

Participant's name:

_____

Participant's signature:

_____

Date: _____

Statement by Investigator

☐ I have explained the project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

If the Investigator has not had an opportunity to talk to participants prior to them participating, the following must be ticked.

☐ The participant has received the Information Sheet where my details have been provided so participants have had the opportunity to contact me prior to consenting to participate in this project.

Investigator's name:

_____

Investigator's signature:

_____

Date: _____

Appendix D

Analyses: Multilinear Modelling Tables and Post-Hoc Tables

Table 1.

Tests of Fixed Effects for Purdue Pegboard Performance

Source	df	*F*	Sig.
Intercept	(1, 18)	2028.523	.000
Colour	(1, 18)	.005	.945
Movement	(2, 144)	118.194	.000
Trial	(2, 144)	3.599	.030
Colour * Movement	(2, 144)	2.285	.105
Colour * Trial	(2, 144)	.467	.628
Movement * Trial	(4, 144)	1.041	.388
Colour * Movement * Trial	(4, 144)	1.790	.134

Table 2.

Pairwise Comparison of Movement Type for Purdue Pegboard Performance

Movement	Movement	Mean Difference	df	Sig.	95% CI for Difference
Left	Right	-1.533	144	.000	[-2.105, -.961]
	Bimanual	2.850	144	.000	[2.278, 3.422]
Right	Left	1.533	144	.000	[.961, 2.105]
	Bimanual	4.383	144	.000	[3.811, 4.955]
Bimanual	Left	-2.850	144	.000	[-3.422, -2.278]
	Right	-4.383	144	.000	[-4.955, -3.811]

Table 3.

Pairwise Comparison of Trial Number for Purdue Pegboard Performance

Trial	Trial	Mean Difference	df	Sig.	95% CI for Difference
1	2	-.617	144	.035	[-1.189, -.045]
	3	-.717	144	.014	[-1.289, -.145]
2	1	.617	144	.035	[.045, 1.189]
	3	-.100	144	.730	[-.672, .472]
3	1	.717	144	.014	[.145, 1.289]
	2	.100	144	.730	[-.472, .672]

Table 4.

Tests of Fixed Effects for Reaction Time (ms) of a Pinchgrip Task

Source	df	*F*	Sig.
Intercept	(1, 18)	648.097	.000
Colour	(1, 18)	4.796	.042
Movement	(2, 36)	1.648	.207
Colour * Movement	(2, 36)	.291	.749

Table 5.

Pairwise Comparison of Movement Type for Reaction Time of a Pinchgrip Task

Movement	Movement	Mean Difference	df	Sig.	95% CI for Difference
Left	Right	-.014	36	.123	[-.032, .004]
	Bimanual	.000	36	.989	[-.018, .018]
Right	Left	.014	36	.123	[-.004, .032]
	Bimanual	.014	36	.126	[-.004, .032]
Bimanual	Left	.000	36	.989	[-.018, .018]
	Right	-.014	36	.126	[-.032, .004]

Table 6.

Tests of Fixed Effects for Rise Time (ms) of a Pinchgrip Task

Source	df	*F*	Sig.
Intercept	(1, 18)	315.994	.000
Colour	(1, 18)	.043	.838
Movement	(2, 36)	.369	.694
Colour * Movement	(2, 36)	.659	.524

Table 7.

Pairwise Comparison of Movement Type for Rise Time of a Pinchgrip Task

Movement	Movement	Mean Difference	df	Sig.	95% CI for Difference
Left	Right	.008	36	.596	[-.024, .041]
	Bimanual	-.005	36	.755	[-.037, .027]
Right	Left	-.008	36	.596	[-.041, .024]
	Bimanual	-.013	36	.401	[-.046, .019]
Bimanual	Left	.005	36	.755	[-.027, .037]
	Right	.013	36	.401	[-.019, .046]

Table 8.

Tests of Fixed Effects for Maximum Force (a.u.) of a Pinchgrip Task

Source	df	*F*	Sig.
Intercept	(1, 18)	204.536	.000
Colour	(1, 18)	1.107	.307
Movement	(2, 36)	.945	.398
Colour * Movement	(2, 36)	1.559	.224

Table 9.

Pairwise Comparison of Movement Type for Maximum Force of a Pinchgrip Task

Movement	Movement	Mean Difference	df	Sig.	95% CI for Difference
Left	Right	-.018	36	.288	[-.051, .016]
	Bimanual	.003	36	.844	[-.030, .036]
Right	Left	.018	36	.288	[-.016, .051]
	Bimanual	.021	36	.210	[-.012, .054]
Bimanual	Left	-.003	36	.844	[-.036, .030]
	Right	-.021	36	.210	[-.054, .012]